1988 End-of-Fiscal Year Report

Robert F. Beck, Project Director

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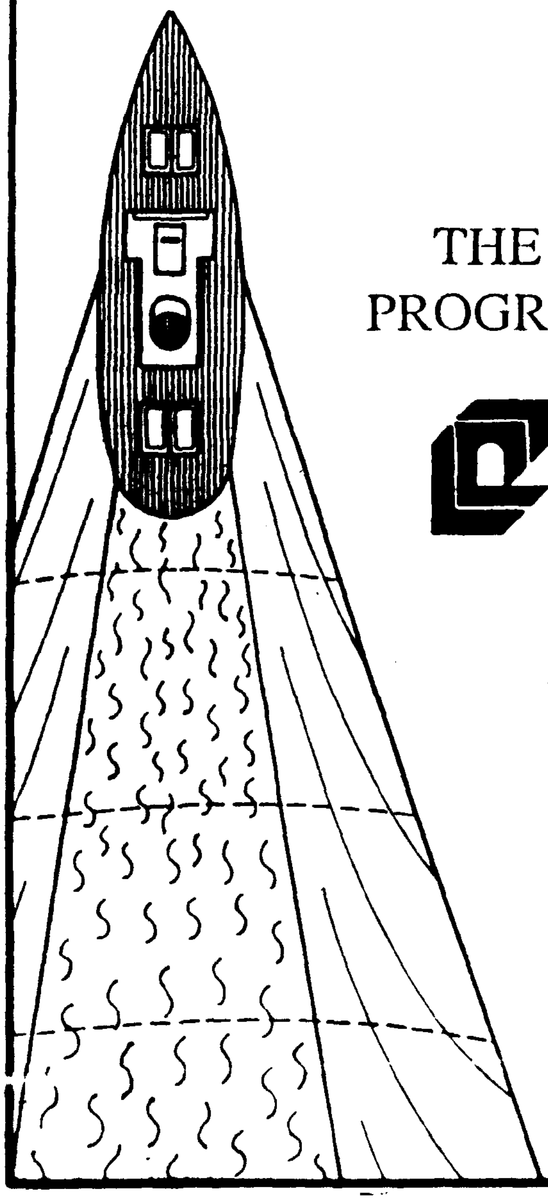

THE UNIVERSITY OF MICHIGAN
PROGRAM IN SHIP HYDRODYNAMICS

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ERIM

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Statement A per telecon Dr. Edwin Rood
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PROGRAM IN SHIP HYDRODYNAMICS

Executive Summary Report

by

Robert F. Beck, Project Director

The second year of the Program in Ship Hydrodynamics has continued the success of the first year. There were budget cut difficulties early in the year, but they have been resolved and in general the research is progressing well. Appendix I lists the year-end reports written by the principal investigators for each of the research projects. These reports summarize the research goals, significant accomplishments of the past year and proposed research for next year. As part of the budget resolution, projects 3.3.1 (Nonlinear Ship Waves) and 3.3.3 (Nonlinear Waves and Wave Interaction) were combined into a single project 3.3.1 (Nonlinear Ship Waves). Only the combined project is listed in Appendix I. Also presented is pertinent information such as publications and a list of participants in each project. In the second appendix are the abstracts from papers published or submitted for publication during the past year.

During the past year much effort has gone into modifications to the Ship Hydrodynamics Laboratory (the towing tank) to make it more suitable for the PSH. Several offices and rooms have been switched to make space for a clean room in which the laser instrumentation can be assembled. In addition, the quality of the water surface in the towing tank has been greatly improved. Three more surface skimmer heads have been added. Several sources of the oil and grease which make up the surface film have been identified and isolated. In conjunction with the Remote Sensing Laboratory of the School of Natural Resources we are trying to develop a system to continuously monitor the surface quality using reflectance of the water surface and a spectroradiometer.

Significant progress has been made on the acquisition of the major pieces of experimental equipment for the towing tank. The Hydrodynamic Monitoring Facility (HMF) is being designed and built by the Space Physics Research Laboratory. It uses lasers to measure the surface slope, height, and velocity in the wake region of a model. At the present time, all system components are complete and are being bench tested. The HMF should be available for demonstration in the towing tank at the November meeting. For a variety of reasons, the capabilities of the system are not as originally proposed. As discussed in the year-end report for Project 3.1.1, the number of warm spots has had to be significantly reduced and the accuracy degraded slightly. These changes will make the experiments to be conducted using the HMF more difficult, but will not alter the fundamental hydrodynamic properties of the ship wake which are to be investigated.

The three component Laser Doppler Anemometer (LDA) is presently being built by TSI and is scheduled for completion in November. The system is unique in the fact that it uses fiber optics, wet mirrors and has a 1200mm stand-off distance of the measurement volume. Doppler burst processors have been mated with the LDA interface which has been built and the system is in operation. The traversing system has been designed and various components purchased. The LDA will initially be tested in a small towing tank in the Gas Dynamics Laboratory and then moved to the large towing tank at the Ship Hydrodynamics Laboratory.

Several sets of experiments were completed in the past year. ERIM has conducted a series of scatterometer measurements in the towing tank to study Bragg wave decay. A plunger wavemaker driven by an acoustic speaker was used to generate very short waves. The frequency of the wavemaker was adjusted to peak the radar return signal. The wavemaker was then progressively moved farther away from the radar footprint. The reduction in backscatter was found to be slightly greater than what would be expected due to viscous decay. This was attributed to surface film effects in the tank. Further detailed measurements will await the completion of the HMF.

Most of the experimental research conducted during the past year involved investigations of the interactions of vorticity with the free surface using advanced flow visualization techniques. Prof. Bernal continued his investigation of the interaction of an underwater jet with the free surface. He has also initiated a study of the break-up of a vortex ring as it impinges on the free surface at various angles. Prof. Willmarth has been studying the interaction of a pair of vortices with the free surface. The pair of vortices are generated by either a delta wing traveling below the free surface or a specially designed flapper device. All the experiments have shown the strong interactions which occur between the vorticity and the short wavelength waves on the free surface. The short wavelengths are believed to be a major source of radar backscatter. Another important aspect of the interaction involves the advection of vorticity from below the surface to the free surface. This advection of vorticity to the free surface must be accompanied by the transport of fluid from below the surface to the free surface, thus possibly altering the temperature and chemical composition of the free surface.

To complement the experimental investigations into the interaction of vorticity with the free surface Prof. Tryggvason has been using numerical techniques to simulate the interactions. The results for a pair of vortices approaching the free surface have been compared with Willmarth's experiments and good agreement found. To bring in three-dimensional effects the interaction of a vortex ring as it approaches the free surface is being studied. The results will be compared with Bernal's experiments.

The final analytic task under the PSH is to investigate nonlinear ship waves and wave interactions. Several different subtasks have been supported under the general project 3.3.1 (Nonlinear Ship Waves). Because the study of nonlinear waves involves the solution of very difficult numerical problems, several subprojects have focused on numerical methods to solve water wave problems. Particularly promising are the use of an overdetermined system of equations and the desingularization of the boundary integral equation by removing the singularities from the boundary surface. These techniques have been developed by Prof. Schultz and are being applied to the problem of a body moving below a free surface. Future work will include bodies piercing the free surface; however, this involves the added complexity of the contact line between the water surface and the body surface. In order to study the flow in the contact region, the impulsive wavemaker has been examined. A uniformly valid solution for a broad class of wavemaker-velocity functions has been developed.

Also conducted under the nonlinear wave project has been work on wave/wave interaction and the effects of surface tension and viscosity on wave damping. A formal boundary layer procedure has been used to solve for damping coefficients of slightly viscous linear waves. A new closed-form solution for capillary-gravity wave damping has been obtained.

There continues to be strong interaction between the Navy laboratories, the PSH and other research institutions. During the past year there have been four outside speakers for the PSH seminar series. The Ship Wake Consortium had their fall workshop on the 4th and 5th of October, 1988, at The University of Michigan. The agenda for the workshop is in Appendix III. As can be seen from the titles of the talks, there is a great deal of interrelationship between the various research topics that are being studied. The Consortium has played a very valuable role in bringing together the researchers who are working on the ship wake problem.

Several PSH researchers have been involved in the Navy's full scale ship wake experiments. It is imperative that the wake data collected in the towing tank at model scale be correlated with full scale results. The full scale data that are being collected will be invaluable in this regard. In fact, there will be three scales of data available to examine scaling questions. Very small scale data is being collected in the small tanks in the Gas Dynamics Laboratory. Intermediate scale data will be obtained from the Ship Hydrodynamics Laboratory towing tank and full scale data from the Navy trials.

3.1.1 Hydrodynamic Monitoring Facility (HMF)

Principal Investigator: G.A. Meadows

RESEARCH SUMMARY

Description of Scientific Research Goals: To make substantial progress in the understanding of the hydrodynamic mechanisms which allow ship generated disturbances to be remotely sensed, experimental measurements which can correlate the hydrodynamic properties of the flow field with the electromagnetic properties of the sensing field are necessary.

To make these types of measurements, specialized facilities have been developed. This research effort has concentrated on the development of new, rapid, and accurate instrumentation to measure surface tangential velocities, surface displacements, and surface slopes of the water surface in a controllable region. The goal is to compare these observations with benchmark hydrodynamic studies and to eventually correlate these measurements with simultaneous radar scatterometer measurements. Such a complete set of data has never been gathered in a controlled environment. It will allow space and/or time correlations to be made of the hydrodynamic surface properties, the radar signature and the infrared signature.

Project 3.1.1 has developed a set of three instruments to measure the free surface height, slope and tangential velocities concurrently. The slope will be determined using refracted laser light. The surface height and tangential velocities will be measured using a thermal image to track "warm spots" which will be created on the free surface by a powerful laser pulse. The warm spots will be aligned in different patterns under computer control to obtain linear velocity profiles, vorticity, or divergence on the free surface.

Significant Results in the Past Year: In the first year of this effort, development of these three new instruments has proceeded from the concept stage through final design and fabrication. During year II extensive testing, redesign and continued development of the three primary sensing systems has comprised our major effort. As testing of the HMF has progressed several difficult technical problems have arisen. These problems center around through-put efficiency of visible and I.R. systems. In order to achieve the speed necessary to accomplish the scientific measurements, "cutting edge" optical devices are employed throughout the instrument design. In many instances these devices are far from the state of fully developed commercial components. The impact on our instrument development program has been a long test and re-development effort (from the specified systems) and a reduced capability for the final instrument. To access the impact of these design and capability changes technical discussions were held in July 1986. As a result of these discussions, it was agreed that the minimum scientifically acceptable instrument performance is the following:

Sample spacing: 1cm or less
Sample rate: 10Hz or better
Sample grid: 10 x 10 points in < 0.1 sec.
Scan area: 0.4 x 0.4m
Surface height resolution: better than 2mm
Surface velocity resolution: 1mm/sec
Surface slope resolution: 0.2°
Spot to spot centers: 5 to 10mm

Final testing of the assembled HMF is presently underway with a demonstration of capabilities planned for the annual review scheduled for November 4-5, 1988. At that time a simple sinusoidal wave of known form will be simultaneously imaged by both the HMF and by conventional instrumentation to provide comparisons of wave height, wave slope and surface velocity.

The entire instrument was designed to be transportable so that it can be bench tested outside the towing tank. In addition, it will be able to be moved to other laboratories to conduct specific experiments of joint interest.

The acquisition and programming of the data acquisition control and computer systems is nearly completed. This computer controls the active sensors of the systems and eliminates carriage motion to cast the data in a true inertial reference frame independent of model speed. The data acquisition and analysis computer, a MicroVax, was chosen to provide complete compatibility with Navy laboratories to foster data exchange.

Plans for Next Year's Research: It is anticipated that after testing of the HMF in the Ship Hydrodynamics Laboratory in November, the detailed calibration effort will begin. This effort, however, will be carried out jointly by the research and engineering staff. Once this activity has been completed, initial measurements of fundamental wave and current fields will begin. This effort will be designed to corroborate benchmark one-dimensional measurements made elsewhere by other researchers. The ERIM activities (project 3.1.2) have been scheduled to coincide with the date of operational status of the HMF. At that time coincident hydrodynamic and microwave measurements will begin. Once again, measurement of fundamental flows and wave structures will be initially attempted followed by more complex patterns.

LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

   none

2. Technical Reports

   none

3. Presentations

   none

LIST OF HONORS/AWARDS

none

LIST OF PARTICIPANTS

Guy A. Meadows, Associate Professor
John Dombrowski, Research Engineer
Brian Kennedy, Sr. Research Engineer
Tom Litow, Sr. Research Associate
Museok Song, Ph.D. student
Eric Wright, Research Associate
Zhijian Wu, Ph.D. student

3.1.2 ERIM Cooperative Research Program

Principal Investigator: J.D. Lyden and R.A. Shuchman

RESEARCH SUMMARY

Description of Scientific Research Goals: The long-term research goal of the Environmental Research Institute of Michigan's (ERIM's) involvement in the PSH is performing multi-frequency, multi-polarization calibrated scatterometer radar measurements simultaneously with the University's Hydrodynamic Monitoring Facility (HMF). These measurements will represent the first multi-frequency (1 to 100 GHz), multi-polarization (V and H, like and cross), radar measurements of a well characterized water surface (elevation and currents). We expect these measurements to provide a critical data set which should help resolve the controversy surrounding radar scattering models of the ocean's surface and ship wakes. We are planning to extend these results to help explain the ship wake signatures often observed in Synthetic Aperture Radar (SAR) imagery.

Significant Results in the Past Year: The research goals of our second year activities were to perform a series of scatterometer measurements in the towing tank to help familiarize ourselves with the operational considerations of the environment. These measurements were performed in anticipation of a more comprehensive measurement program once the HMF instruments are operating. The scatterometer measurements we did perform were designed to study Bragg wave decay, surface film effects, and long wave/short wave interactions.

The scatterometer measurements were performed at C-band (5 GHz) with vertically-transmitted and received polarization. The antenna height was 3m above the water's surface with an incidence angle of 45°. The antenna footprint on the water's surface was 1.6m. On either side of the radar footprint, three capacitance wave probes were used to make wave measurements. These probes provide adequate wave measurements up to about 10 Hz. The wavemaker we used in our study was a plunger driven by an acoustic speaker. This system was capable of generating waves from about 4 to 15 Hz. The choice of C-band over X-band (10 GHz) and L-band (1.5 GHz) was our ability to both generate and measure Bragg waves at this frequency. Once the wave and current measurement equipment is operating, we expect to make radar measurements at all three frequencies.

To study Bragg wave decay, the frequency of the wavemaker was adjusted to peak the radar signal. The wavemaker was then progressively moved farther away from the radar footprint. The reduction in backscatter was found to be slightly greater than what would be expected due to viscous decay. The surface film effects were investigated by keeping the wavemaker and radar fixed, and making measurements over a long period of time. Due to the large size of the tank and its construction properties, it is not possible to maintain a clean water surface. Prior to our measurements, the surface was skimmed to remove films. However, these films would eventually reappear and corrupt our measurements. Results indicate that repeatable measurements were possible for approximately the first hour after skimming. This effect provides an operational limitation which will be addressed prior to making higher frequency measurements where film effects are more pronounced. Subsequent to our measurements, several sources of the surface contaminants were discovered and fixed. This significantly reduced the formation of surface films in the tank. Long wave/short wave interactions were studied by mechanically generating long waves which would overtake the acoustically-generated waves in the radar footprint. These data have not been analyzed but should provide information on the hydrodynamic modulation of the short waves by the long waves.

The above measurements were performed to gain experience operating in the towing tank environment. These measurements provided insight into the problems we will have to address prior to future measurement programs. We are presently planning to perform a more detailed set of multi-frequency measurements when the wave and current measuring equipment is operating.

Plans for Next Year's Research: Our plans for next year are centered around the University's Hydrodynamic Monitoring Facility (HMF). We anticipate a comprehensive radar measurement program coincident with HMF measurements of towed model ship wakes and other wake-related phenomena. We also anticipate comparing our laboratory measurements with results from the ONR surface ship wake detection program which is studying these phenomena at full-scale.

LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

   none

2. Technical Reports

   none

3. Presentations

   Lyden, J.D., Meadows, G.A., Shuchman, R.A., and Onstott, R.G., Scatterometer Measurements of Small-Scale Waves, Proceedings of International Geoscience and Remote Sensing Symposium, Edinburgh, Scotland, September 1988.

LIST OF HONORS/AWARDS

none

LIST OF PARTICIPANTS

J. Lyden, ERIM
R. Shuchman, ERIM
S. Kilberg, graduate student
K. Dailey, student

3.2.3 Large Scale Structure in Ship Wakes

Principal Investigator: W. W. Willmarth

RESEARCH SUMMARY

Description of Scientific Research Goals: The problem addressed in this research is that of the experimental and theoretical investigation of the large scale structure of the three-dimensional turbulent flow in boundary layers and wakes produced by surface ships. The investigation is designed to provide basic information about the fundamental flow processes beneath and near the surface in the vicinity of the ship hull and propulsion system and in the resulting unsteady turbulent flow far downstream. It should then be possible to identify the flow processes responsible for the wake signatures of surface ships. The facilities and equipment for this research are being developed and used jointly with Professor Bernal in his parallel investigations of the "Vortical Structure of Ship Wakes" (3.2.6).

The present investigation of the flow beneath the surface will be correlated with the results of measurements of the surface flow field in the wake using the Hydrodynamic Monitoring Facility equipment developed by G. Meadows in section 3.1.1.

The primary goal of this research is to obtain as broad an understanding as possible of the dominant characteristics of the large scale structure of the flow field in the wake of a ship.

Significant Results in the Past Year: Facilities and Flow Measurement and Visualization Equipment - During the time from October, 1987 to September, 1988, we developed and built the equipment and instrumentation that is now being used for experimental measurements in this investigation (3.2.3 Large Scale Structure of Ship Wakes). Much of this equipment is shared with the related program 3.2.6 Vortical Structure in Ship Wakes conducted by Professor Bernal. The major items of equipment are a 2.5 x 2.5 x 5 foot tank with glass walls (constructed by Bernal and Research Assistant Koorosh Madnia), a small towing tank 2.5 x 2.5 x 24 feet (constructed by Willmarth and R. A. Amir Hirsa) which is fitted with a wave development tank 2.5 x 8 x 10 feet in the center part of the towing tank, a 20 watt Copper Vapor Laser and a 5 watt Argon-Ion Laser for flow visualization, an image analysis system (NSF Grant and cost sharing with the University, no charge to ONR) with system software developed by Bernal, hot-film probes, a traversing system and an IBM PC/AT with Le Croy data acquisition equipment for future use with a laser Doppler anemometer (LDA) as discussed below.

Laser Doppler Anemometer:

Much time and effort has also gone into the design of a 3-Component fiber optic laser Doppler anemometer. In the course of developing specifications for the LDA system it became clear that the LDA should be built by a commercial vendor and that Professors Bernal and Willmarth had the expertise to put together the rest of the LDA system. A considerable amount of money will be saved by building our own traverse system (Willmarth), LDA interface to the storage media and controlling computer (Bernal) and the FORTRAN system software (Bernal, Willmarth and R.A. Doug Anthony). The economies were so great that we have been able to afford to purchase a Copper Vapor laser and an analog to digital converter (Le Croy). The LDA system was ordered from TSI October 11, 1987, and is scheduled for completion in October 1988. The LDA interface has been built and is in operation. The first version of the the software is written and running. The traverse system drive is purchased, assembled and running. The mechanical components of the traverse are designed and two axes (rotation and translation normal to the LDA axis) will be finished at the end of October 1988. A short paper describing the design of the LDA system has been written and was presented in October 1987, at the International Towing Tank Conference in Tokyo, Japan.

Experimental Measurements:

After completion of the towing/wave tank, we initiated an investigation of the wake and wake signature produced by a delta wing moving parallel to the surface with downward lift. The primary large scale structure in this wake consists of a pair of counter-rotating vortices which propagate towards the surface and then produce surface deformations called striations and scars (these were first identified by Sarpkaya). In addition to the surface motion, the vortex pair also contains fluid from the region below the surface that is ingested during vorticity generation and roll-up. This fluid is deposited on the surface during interaction of the vorticity with the surface.

To study these phenomena we are photographing the motion of small suspended particles or fluid containing fluorescent dye using sheets of laser light in the wake (we use both Argon-Ion and Copper Vapor lasers). The motion of the suspended particles is measured by particle tracking and/or the laser speckle-gram technique. For more detailed study, we have invented and constructed a new vortex pair generator, using a pair of rotating flaps, which produces a two-dimensional vortex pair under controlled conditions. The process of roll-up, propagation and fluid transport towards the surface, fluid deposition on the surface and generation of motion of the free surface is now being studied with this apparatus.

We have also been meeting with Professor Gretar Tryggvason and his R. A., Mr. D. Yu to discuss computations of the above phenomena. A single experimental realization of the roll-up of vorticity, fluid ingestion and subsequent propagation of the vortex pair towards the free surface has been numerically simulated with good agreement between experiment and computation up to the time that the vortex pair becomes turbulent when it approaches the free surface. A letter describing these initial results has been written and accepted by Physics of Fluids.

Recently, we have also found that the phenomenon of surface contamination by mono-molecular surface films has a very great affect on the actual fluid flow just beneath the surface, as well as the better known effect on the surface motion and wave damping.

Plans for Next Year's Research: We plan to continue the study of the flow and surface motions produced by the wake of a delta wing in the small towing tank. The study of vortex pairs propagating towards and interacting with the surface will be completed during the next year. Both studies will use flow visualization and laser speckle-gram measurements.

The calibration, check out and use of the LDA will be performed during research measurements on the flow field in a turbulent jet moving parallel and near a free surface. This will begin as soon as the LDA arrives. Complete measurements of the three-dimensional turbulent velocity field (all nine components of the Reynolds stress can in principal be measured) will be attempted. This investigation will complement the presently almost complete study of the turbulent jet with one component measurements of the velocity field that is being done by Koorosh Madnia.

LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. <u>Papers Publications in Refereed Journals</u>

Willmarth, W. W., "Design of Three Component Fiber Optic Laser Doppler Anemometer for Wake Measurements in a Towing Tank", <u>Proceedings</u> of International Towing Tank Conference in Tokyo, Japan, October 1987.

Willmarth, W.W., Tryggvason, G., Hirsa, A. and Yu, D., "Vortex Pair Generation and Interaction with a Free Surface", accepted for publication in <u>Physics of Fluids</u> as a Letter.

2. <u>Technical Reports</u>

none

3. <u>Presentations</u>

"Design of Three Component Fiber Optic Laser Doppler Anemometer for Wake Measurements in a Towing Tank", International Towing Tank Conference in Tokyo, Japan, October 1987.

LIST OF HONORS/AWARDS

none

LIST OF PARTICIPANTS

William W. Willmarth, Professor
Luis P. Bernal, Assistant Professor
Gretar Tryggvason, Assistant Professor
Amir Hirsa, Graduate Student
Douglas Anthony, Graduate Student on leave from David Taylor Model Basin
Dave Bass, Undergraduate Student no longer with project

3.2.5 Flow Visualization of Turbulent Burst

Principal Investigator: K.-P. Beier

RESEARCH SUMMARY

Description of Scientific Research Goals: The major goal of this project is to gain a better understanding of the details of turbulent burst by using advanced computer graphics methods to analyze existing data. This goal involves the development of a new visualization concept for the graphical representation of a turbulent channel flow. The flow is described by its properties (like velocity vectors) given on a spatial grid as a function of time. The loci of constant property magnitude are complex three-dimensional surfaces. These surfaces are changing their shape in time. The surfaces can be calculated from the given data set and can be used to build an 'onion' model of several surface layers each representing a different constant property magnitude. The layers can be displayed as translucent surfaces and can be animated in time. The visualization principle can be applied to various flow properties like velocity, pressure, vorticity, etc.

Significant Results in the Past Year: After algorithms for deriving a wire frame representation of the contour surfaces had been successfully developed during the first year of the project, the past year concentrated on methods for a surface-oriented representation in order to allow for hidden surface removal, coloring/shading, and the display of translucent surfaces. The three-dimensional surfaces of interest show extreme complexities regarding the geometric properties. After an intensive literature search, a suitable method with sufficient efficiency could not be found among the many existing techniques.

A new approach for deriving a surface-oriented representation was developed and implemented. This approach uses a topological search algorithm to find the intersection of a contour surface with each of the volume elements defined by the spatial grid. For a non-zero intersection, the method will deliver a closed polygon representing an element of the contour surface. Since these polygons are usually non-planar, a triangulation method is used to subdivide the polygon in planar triangles. As a final result, the contour surface is represented by a large number of triangles. This is the most effective surface representation for subsequent processing regarding hidden surface removal, coloring/shading, and translucent display. The first tests using simplified surfaces are promising. It is expected that a triangular representation of a more complex surface will be available in the near future.

The effectiveness of the triangular representation method is based on a newly developed data structure. During the report period, most of the time was spent on the development of these structures. Effective data storage and data handling is instrumental for the practical usefulness of the visualization tool. The new data structure made it possible to implement an important new user option. Using two sets of three orthogonal planes, the user can interactively define any rectangular sub-volume within the flow volume and separate this sub-volume for a detailed inspection. A special volume clipping algorithm was designed and implemented allowing for a fast sub-volume generation. Another option developed allows the use of stereoscopic viewing techniques in order to improve the understanding of the complex spatial distribution of flow properties. Presently, the usefulness of this technique and its integration in the visualization concept is under investigation.

During the report period, it became more and more obvious that the limited capability of the available hardware equipment (an IRIS Workstation from Silicon Graphics) will place severe restrictions on the future progress of this project. This was one of the reasons for the Principal Investigator to submit a proposal to DoD's DURIP (Defense University Research Instrumentation Program) for a $270,265 "Visualization Facility for Computational Fluid Dynamics". The proposed facility will provide extremely high computational power combined with high-speed three-dimensional graphics. Specialized video equipment will allow the production of videotapes and the generation of animated sequences from frame-by-frame calculations. The proposed visualization facility will be used by several DoD sponsored projects within The University of

Michigan. Primary user will be the Project in Ship Hydrodynamics including this project "Flow Visualization of Turbulent Burst". The proposal has been approved at a reduced budget (a total of approximately $200,000). The visualization facility will be in place around December '88 / January '89.

Plans for Next Year's Research: The new hardware equipment available for this project during the next year will require adjustments in the already developed program code in order to make use of a multi-processor architecture and a more sophisticated graphics environment. The method for a triangular surface representation will be completed and optimized. Using special hardware features of the new equipment (z-buffer and hardware supported shading on a pixel level), a realistic surface representation with hidden surfaces removed and a lightening model applied will be implemented. Towards the end of next year's research, a first 'onion' model of a turbulent flow is expected to be operational. With this tool in place, intensive studies on turbulent flow characteristics can then be started.

LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

none

LIST OF HONORS/AWARDS

Teaching Excellence Award 1988, College of Engineering, The University of Michigan.

LIST OF PARTICIPANTS

Klaus-Peter Beier, Associate Professor
S.H. Han, Graduate Student
C. Churchill, System Research Programmer II

3.2.6 Vortical Structure of Ship Wakes

Principal Investigator: L.P. Bernal

RESEARCH SUMMARY

Description of Scientific Research Goals: The main objective of this project is to obtain a better understanding of the turbulent viscous wake of surface ships and underwater vehicles by means of an experimental investigation of the underlying large scale vortical structure and its dynamics. The research has continued along two main areas: (1) development of speckle photography for flow field velocity measurement, and (2) experimental investigation of the interaction of a turbulent round jet with the free surface.

The development of flow field measurement techniques like Laser Speckle Photography is motivated by the need to obtain velocity field information so that the vorticity can also be determined. This vorticity field information is essential to the understanding of the dynamics of the large scale structures near the free surface.

The investigation on the interaction of a turbulent jet with the free surface was initiated in an effort to obtain some basic data on the nature of the surface disturbances produced by a turbulent shear flow as well as to document the effect of the free surface on the dynamics of the turbulent flow. This flow configuration was chosen because of its simple geometry while it typifies the flow field associated with the propeller wake.

Significant Results in the Past Year: Laser speckle photography was demonstrated in several flow experiments. These include surface flow velocity measurements in water and velocity field measurements in air. A systematic study was completed to determine the effects of seeding, optical resolution and film resolution on the characteristics of speckle images. The results clearly establish the feasibility of high sensitivity film (ASA 100 - ASA 400) for speckle velocity measurement.

Surface flow velocity measurements were obtained in the interaction region of an underwater jet with the free surface using Laser Speckle Photography. The Speckle Photographs were obtained using a shadowgraph imaging system and a free surface imaging system. The former provides simultaneous visualization of the surface deformation and quantitative data on the velocity field. The later provides a larger field of view and better quality of the speckle images. A speckle photograph of the jet/free-surface interaction obtained with the surface imaging optical system was analyzed to determine the velocity and vorticity field at the free surface. The results demonstrate the generation of vorticity normal to the free surface as a result of the interaction. The mechanism of generation of this vorticity is not clear at this time. It is an important aspect of the interaction since it may involve advection of vorticity from below the surface to the free surface.This advection of vorticity to the free surface must be accompanied by transport of fluid from below the surface to the free surface, thus possibly altering the chemical composition of the surface.

To obtain a better understanding of the mechanism of vorticity generation at a free surface, an investigation of the interaction of vortex rings with the free surface was initiated. Laser Speckle photography will be used to determine the velocity and vorticity field through the interaction process. Graduate student J. T. Kwon will be conducting his PhD Dissertation on this subject. Preliminary results have been obtained for the case of a vortex propagating parallel to the free surface. The most striking feature of the interaction is the vortex reconnection process at the free surface. A new vortex ring facility was designed and constructed to generate vortex rings propagating at an arbitrary angle relative to the free surface. Flow visualization experiments are currently underway in this facility.

Progress continued on the investigation of the interaction of a turbulent jet with the free surface. During the past year experiments were conducted to determine the flow velocity below the surface and the cross-correlation coefficient of the surface curvature fluctuations and the water velocity fluctuations. These experiments were conducted at several jet exit depths and velocities. Early results of these experiments were reported at 17th Symposium on Naval Hydrodynamics. In addition, measurements have been conducted in the case of a round jet moving parallel to a solid flat surface. These results show the very significant differences in flow dynamics at a free surface compared to a solid surface. Also during this past year, design of a surface slope meter was initiated. In this design, the free surface is probed by a narrow laser beam. The reflected light at the free surface is collected by an optical system and imaged into a two-dimensional position detector to determine the surface slope. The optical system is designed to provide a slope measurement independent of the free surface elevation.

Plans for Next Year's Research: During the next year, the analysis of the data on the jet/ free surface interaction experiments will be concluded and the results reported. Experiments will be conducted to characterize the evolution of vortex rings near a free surface. Flow visualization and speckle photography will be used to determine the evolution and velocity field of the vortex rings. The surface slope meter will be constructed and tested. A simple experiment will be conducted to determine the accuracy and resolution of the instrument.

LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

   Bernal, L.P. & Kwon, J.T. "Surface flow velocity field measurement by laser speckle photography", Proc. 4th Int. Symp. on Applications of Laser Anemometry to Fluid Mechanics, 11-14 July 1988, Lisbon, Portugal, to be submitted to Experiments in Fluids.

   Bernal, L. & Madnia, K., "Interaction of a turbulent round jet with the free surface", Proc. 17th Symp. on Naval Hydrodynamics, 29 August - 2 September 1988, The Hague, The Netherlands.

   Bernal, L.P. & Kwon, J.T., "Vortex ring dynamics near a free surface", submitted to 41st Meeting American Physical Society, Fluid Dynamics Division, Nov. 20-22, 1988, Buffalo, NY, to be submitted to Physics of Fluids.

2. Technical Reports

   none

3. Presentations

   Madnia, K. & Bernal, L., "Interaction of an axisymmetric turbulent water jet with the free surface", Bull. Am. Phys. Soc., Vol. 32, No. 10, p. 2045, 1987. (Abstract only)

   Bernal, L., Kwon, T.J. & Wolter, J., "Digital image analysis technique for speckle velocity measurements", Bull. Am. Phys. Soc., Vol. 32, No. 10, p. 2031, 1987. (Abstract only)

   Madnia, K. & Bernal, L. "Dynamics of turbulent jets near a free surface", submitted to 41st Meeting American Physical Society, Fluid Dynamics Division, Nov. 20-22, 1988, Buffalo, NY.

LIST OF HONORS/AWARDS

none

LIST OF PARTICIPANTS

L. P. Bernal, Assistant Professor
W.W. Willmarth, Professor
K. Madnia, PhD Student
J.T. Kwon, PhD Student
S. Aissi, Graduate Student
M. Mizukani, Undergraduate Student

3.3.1 Nonlinear Ship Waves

Principal Investigator: W.W. Schultz

RESEARCH SUMMARY

Description of the Scientific Research Goals: We intend to study the fully nonlinear ship wave problem using a boundary integral method with panels on the ship (with sinkage and trim) and on the actual free surface. Ultimately, we wish to be able to incorporate vorticity, subgrid models of capillary waves (based on the analytical subtasks of this project), and empiricism from tow tank data into the program to get a more accurate representation of the wake SAR signature.

Toward that goal, we are now concentrated on improving two-dimensional calculations to fully examine capillary-gravity wave behavior and developing boundary integral techniques to study nonlinear waves caused by moving bodies beneath the free surface.

Significant Results of the Past Year: PSH technical report 88-01 entitled, "Solution of Potential Problems Using an Overdetermined Complex Boundary Integral Method", by W.W. Schultz and S.W. Hong has been accepted for publication. This detailed analysis of boundary integral solutions of the potential equation shows higher convergence for the least squares formulation. We have continued to perform algorithm modifications that show exponential convergence for some cases. One of these modifications, a spectral trapezoidal method modified from Baker (1982) is shown to be less stable than a method similar to that proposed by Roberts (1983). With this newest spectral method, we have been able to time march with steady translating capillary gravity waves.

We have published PSH technical report 88-02 entitled, "An Alternative Complex Boundary Integral Method for Nonlinear Free Surface Problems", by S.W. Hong, W.W. Schultz, and W.P. Graebel and submitted it for journal publication. This formulates the free surface boundary conditions in terms of velocity, which has several important advantages, especially when vorticity is present. A related manuscript with extensions to three dimensions entitled, "On the Boundary Integral Formulation of Free Surface Problems", by G. Tryggvason, S.W. Hong and W.W. Schultz is nearing completion.

S.W. Joo presented a talk at the Third International Workshop on Waves and Floating Bodies at Woods Hole in March entitled, "Evolution of Nonlinear Waves Due to a Moving Wall", by S.W. Joo, W.W. Schultz and A.F. Messiter. A simple decomposition of the linearized problem allows a uniformly valid solution for a broad class of wavemaker-velocity functions. Far from the wavemaker, we obtain the solution of Chwang (1982) and near the corner for small time our results become identical to that obtained by the local solution of Roberts (1988). We show that his impulsive wavemaker solution is not uniformly valid at the contact line since nonlinear terms must arise immediately.

We have developed a new desingularized method for three-dimensional nonlinear free surface problems. This algorithm has been shown to be much more efficient and accurate than Newman's or Hess' and Smith's methods for the simple potential problem of the first time step as a sphere moves near a flat free surface. The sphere is started impulsively and moves toward or parallel to the free surface.

We have re-analyzed the converging wave tank data of Ramber, Barber and Griffin (1984) and reduced by half the scatter in the wave breaking criteria by measuring rms wave heights rather than crest-to-trough heights. A further reduction by more than one-half was obtained by realizing that the breaking criterion is a function of location in the tank. The latter variation can be attributed to the faster growth rates near the end of the tank and has been corroborated by numerical computations.

We have performed a formal multiple scale procedure on capillary-gravity waves in a manner similar to Djordjevic and Redekopp (1977) to form a nonlinear Schroedinger equation. Unlike their result, we examine deep water waves (which is appropriate for short waves) and, hence, our results do not have the limitation of wave amplitude based on the depth. Our scaling allows the study of pure capillary waves as well. A subsequent stability analysis shows a wavenumber range that is stable to Benjamin-Feir type resonance.

A formal boundary layer procedure has been used to solve for damping coefficients of slightly viscous linear waves. These results are identical to Stokes for free surface gravity waves and to Levich (1962) for contaminated surfaces. A new closed-form solution for capillary-gravity wave damping has been obtained.

Plans for Next Year's Research: Within the calendar year, we anticipate that we will start time marching to determine the nonlinear waves caused by a submerged sphere. At the same time we will prepare a manuscript showing the suitability of the desingularized boundary integral method we are presently using.

The spectrally accurate two-dimensional code will be used to examine the interaction of long and short waves. We will now be able to examine some problems that are ill-posed when surface tension is not included, such as the Rayleigh-Taylor and Kelvin-Helmholtz instabilities. We will determine the suitability of developing a three-dimensional version of this spectral algorithm.

We are continuing the analysis of damping of gravity-capillary waves by surface contamination. The boundary-layer analysis will provide new information on damping of nonlinear and deep water waves by the development of a modified nonlinear Schroedinger equation.

LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

Joo, S.W., Schultz, W.W. and Graebel, W.P., "An Alternate Form of the Complex Boundary Integral Method for Nonlinear Free Surface Problems", submitted to the Journal of Applied Mechanics.

Hong, S.W. and Schultz, W.W., "Solution of Potential Problems using an Overdetermined Complex Boundary Integral Method", to appear in the Journal of Computational Physics.

2. Technical Reports

Papoulias, F.A. and Beck, R.F., "WAVEAMP: A Program for Computation of Wave Elevations Created by a Ship Travelling at a Constant Speed", Technical Report #88-03, July 1988.

3. Presentations

Joo, S.W., Schultz, W.W. and Messiter, A.F., "Evolution of Nonlinear Waves Due to a Moving Wall", Third International Workshop on Waves and Floating Bodies, Woods Hole, MA, March 1988.

Schultz, W.W., "An Error Analysis of the Complex Boundary Integral Method with Applications to Gravity Waves", First International Conference on Computational Methods in Flow Analysis, Okayama, Japan, September 1988.

LIST OF HONORS/AWARDS

"Periodic and Aperiodic Steep and Breaking Waves", Young Investigator Award, funded by the Office of Naval Research, Ocean Engineering Division, $150,000 for 36 months starting July 1987.

LIST OF PARTICIPANTS

W.W. Schultz, Assistant Professor
R.F. Beck, Professor
A.F. Messiter, Professor
L. Olson, Assistant Professor
J. Huh, Ph.D. Student
S.-W. Joo, Ph.D. Student
Y. Cao, Ph.D. Student
D. Rowley, Graduate Student

3.3.2 Interaction of Vorticity and Free Surface Flows

Principal Investigators: G. Tryggvason

RESEARCH SUMMARY

Description of Scientific Research Goals: To contribute toward the understanding of the interaction of vortical flows and the free surface. Particular emphasis is on the surface signature of unsteady flows, and how surface waves are generated and modified. This understanding is sought by considering idealized model problems where the various mechanisms may be isolated. Generally the model equations, even for fairly "clean" problems, are inherently nonlinear and numerical techniques are the only feasible solution method. Our study employs generalized vortex methods and boundary integral techniques. Where applicable, these methods are generally far superior to any other known methods.

Significant Results in the Past Year: During the first year, we have implemented a method for two-dimensional simulations. A variety of problems involving relatively simple vortical flows have been considered. We have investigated in considerable detail the roll-up of a vortex sheet below a free surface. It has been shown that it is possible to distinguish between three different scenarios for the free surface evolution. Strong and shallow vortex sheets suck the free surface into the fluid, weaker and deeper sheets lead to breaking waves on the surface, and even deeper and weaker vortex sheet cause the generation of surface waves that are relatively short compared with the basic wavelength. This investigation is discussed briefly in a manuscript "Deformation of a Free Surface Due to Vortical Flows" published as a Letter in the Physics of Fluids (May, 1988). A more detailed description, discussion of the transition from one regime to another, as well as aspects of the numerics is in preparation. This latter manuscript will also discuss methods to represent the evolution by a simple point vortex model that may be studied analytically.

We are currently studying the formation of a vortex pair and their interaction with the free surface. This investigation is being conducted in close collaboration with Prof. Willmarth and we are trying to model his experimental set-up as closely as possible in order to make detailed comparisons. Preliminary comparisons are promising, but conclusive results require refinements in the experimental set-up. Surface tension has recently been implemented, and currently we are studying its effect on these problems.

To investigate the full three-dimensional interaction of a vortex ring, we are proceeding along two paths. The simpler approach is to model the free surface as a no-slip boundary and the vortex ring as a single vortex filament. We have done several simulations with this model, and results are in rough agreement with preliminary experiments in the AERO watertank. For head-on collision, and near head-on collision, the ring expands outward as it approaches the boundary (in a similar way as the vortex pair in the two dimensional simulations), for rings approaching obliquely the ring appears to connect with its image, corresponding to an "opening up" process. This simple model is inadequate to account for the detailed interactions and the wave generation. To address these problems, we are currently implementing fully three dimensional studies. We have conducted an extensive investigation of boundary integral methods for free surface flows and extended previous work by developing several alternative formulations. A manuscript describing these studies (Tryggvason, Hong and Schultz: "On the Boundary Integral Formulation of Free Surface Problems") is in preparation. An axisymmetric vortex method for homogeneous flows, and weak stratifications has also been completed, but the free surface has not been incorporated as of yet.

A thesis, partly supported by this project, describing a computer model for vortex shedding and wake formation due to a blunt body just under a free surface was defended this spring. An exact linearized solution for vortices traveling beneath a free surface was also obtained, and the computer code tested against it.

Plans for Next Year's Research: We expect that the main thrust in the immediate future will be further work on the three-dimensional code, and applications of the two-dimensional model to problems where the simulations complement the experimental work.

LIST OF PUBLICATION/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

Tryggvason, G., "Deformation of a Free Surface Due to Vortical Flows", Phys. Fluids, Vol. 31, p. 955-957, 1988.

Willmarth, W.W., Tryggvason, G., Hirsa, A., and Yu, D., "Vortex Pair Generation and Interaction with a Free Surface", to appear in Phys. Fluids.

Other Publications

Tryggvason, G., "Vortex Dynamics of Stratified Flows", to appear in Mathematical Aspect of Vortex Dynamics, ed. R. Caflish, SIAM, Philadelphia.

Hong, S.-W., "Unsteady Separated Flows Around a Two-Dimensional Bluff Body Near a Free Surface", Ph.D. Thesis, 1988, Chairman: Prof. W.P. Graebel.

2. Technical Reports

none

3. Presentations

Tryggvason, G., "Free Surface/Vortex Interactions", Ship Wake Consortium Workshop, May 4-5, 1987, DTRC, Washington, D.C., and Sept. 21-22, 1987, University of Michigan, Ann Arbor.

Tryggvason, G. and Yu, D., "Interaction of Vorticity and Density Interfaces", SIAM 35th Anniversary Meeting, October 12-15, 1987, Denver, Colorado.

Tryggvason, G., Yu, D. and Hong, S., "Interaction of Vorticity and Density Interfaces", 40th Meeting of the American Physical Society, Division of Fluid Dynamics, Nov. 20-21, 1987, Eugene, Oregon, Abstract in Bull. Amer. Phys. Soc., Vol. 32.

Tryggvason, G., "Vortex Dynamics of Stratified Flows", SIAM Workshop on Mathematical Aspects of Vortex Dynamics", April 25-27, 1988, Leesburg, Virginia.

Tryggvason, G., "On the Boundary Integral Formulation of Free Surface Problems", SIAM Annual Meeting, July 11-15, 1988, Minneapolis, Minnesota.

LIST OF HONORS/AWARDS

none

LIST OF PARTICIPANTS

G. Tryggvason, Assistant Professor
W.P. Graebel, Professor
D. Yu, Ph.D. Student
M. Song, Ph.D. Student
S.-W. Hong, Graduate with a Ph.D. in May, 1988)

Proceedings of the International Towing Tank Conference
October 18-24, 1987

Design of Three Component Fiber Optic Laser Doppler Anemometer for Wake Measurements in a Towing Tank

by

Professor William W. Willmarth

The design of a unique fiber optic laser Doppler anemometer for towing tank measurements in wakes and boundary layers is presented. The instrument is designed so that it can also be used for measurements in a wind tunnel.

Physics of Fluids

Vortex Pair Generation and Interaction with a Free Surface

by

Professor William W. Willmarth
Assistant Professor Gretar Tryggvason
Graduate Student Amir Hirsa
Graduate Student Dequan Yu

Two vertical, rotating flaps are used to generate a vortex pair beneath a free surface. Vortex pair formation, propagation and interaction with a free surface are described. Numerical simulations for inviscid flow about a *constant upwash sheet of vorticity beneath a free surface agree with experiment up to the time that* turbulent mixing occurs during interaction with the free surface. The spacing between the vortex pairs then becomes larger than the calculated spacing. The experiments and lines of marked particles included in the *simulations show fluid ingestion and transport towards the free surface.*

Proceedings of the 17th Symposium on Naval Hydrodynamics
August 29 - September 2, 1988

Interaction of a Turbulent Round Jet with the Free Surface

by

Associate Professor Luis P. Bernal
Graduate Student Koorosh Madnia

In this paper the results of an experimental investigation on the interaction of the free surface with a turbulent underwater jet are presented. Flow visualization of the free surface showed surface waves generated by the interaction of the jet with the surface at sufficiently high jet exit velocity. Simultaneous visualization of the free surface and the jet fluid indicates that the waves are generated by the interaction of the large scale vortical structure in the jet with the free surface. Also characteristic surface features are observed associated with the turbulent vortical motions in the jet. The amplitude of the surface motion was characterized by surface curvature measurements. The characteristics of the mean flow under the surface are briefly discussed.

Proceedings of the 4th International Symposium on Naval Hydrodynamics
July 11-14, 1988

Surface Flow Velocity Field Measurement by Laser Speckle Photography

by

Assistant Professor Luis P. Bernal
Graduate Student Jung Tai Kwon

A technique for measurement of the velocity field at a free surface is being developed to investigate the interaction of a turbulent underwater jet with the free surface. The technique is similar to Laser Speckle Velocimetry except for the tracer particles and the imaging system used to obtain the speckle photographs. A shadowgraph system and a surface imaging system have been used. The former provides simultaneous visualization of the surface deformation. Typical results of the velocity and vorticity fields at the free surface are presented.

Forty-First Meeting of the American Physical Society, Division of Fluid Dynamics
November 20-22, 1988

Dynamics of Turbulent Jets near a Free Surface

by

Graduate Student Koorosh Madnia
Assistant Professor Luis P. Bernal

The interaction of the free surface with a turbulent round underwater jet has been studied experimentally. Hot film axial velocity measurements were conducted to study the effect of the free surface on the jet turbulence. Mean and rms values of the velocity fluctuation were measured along directions parallel and perpendicular to the surface for several jet depths. The jet flow structure is altered by the interaction with the free surface. The velocity profiles show an increase of the maximum mean velocity compared to the free jet. The jet growth rate in the direction parallel to the free surface is larger by a factor of 1.4 compared to the growth in the direction perpendicular to the surface. Simultaneous measurements of the surface curvature and the jet axial velocity are being conducted to gain additional insight on the mechanisms of generation of surface waves and motions by the jet turbulence.

Forty-First Meeting of the American Physical Society, Division of Fluid Dynamics
November 20-22, 1988

Vortex Ring Dynamics at a Free Surface

by

Assistant Professor Luis P. Bernal
Graduate Student Jung Tai Kwon

We report observations of the interaction of vortex rings with a free surface. Simultaneous flow visualization of the ring fluid and the free surface deformation was obtained using Laser Induced Fluorescence and shadowgraph illumination respectively. The vortex rings were formed one diameter below the free surface with their axis parallel to the surface. The Reynolds number was in the range 103-104. The more striking feature of the interaction is the opening of vortex lines when the upper region of the vortex ring interacts with the free surface. After this stage in the interaction the vortex lines terminate at the free surface. The lower part of the vortex ring also interacts with the surface but vortex lines do not open, possibly because of the velocity field induced by vorticity of opposite sign generated at the free surface. After the interaction the opened up vortex ring is highly elongated and undergoes oscillations of its eccentricity as it propagates downstream.

Journal of Computational Physics

Solution of Potential Problems using an Overdetermined Complex Boundary Integral Method

by

Assistant Professor William W. Schultz
Graduate Student Seok Won Hong

The advantages of solving potential problems using an overdetermined boundary integral element method are examined. Representing a two-dimensional potential solution by an analytic complex function forms two algebraic systems from the real and imaginary parts of the discretized form of Cauchy's theorem. Depending on which boundary condition is prescribed, the real or the imaginary algebraic system is diagonally dominant. Computations show that the errors of the strong system (diagonally dominant) often have almost the same value as those of weak system (diagonally non-dominant) but with the opposite sign. The overdetermined system, composed of the combination of the real and imaginary parts, tends to average these errors, especially for circular contours. An error analysis and convergence studies for several geometries and boundary conditions are performed. A methodology for handling computational difficulties with contour corners is outlined. Further modifications are proposed and tested that show exponential convergence for smooth contours.

Journal of Applied Mechanics

An Alternative Complex Boundary Element Method for Nonlinear Free Surface Problems

by

Graduate Student Seok Won Hong
Assistant Professor William W. Schultz
Professor William P. Graebel

A complex variable boundary element method is developed for potential flow problems by applying Cauchy's integral theorem to the complex velocity. The resulting integral equation is a function of the normal and tangential velocity components on the boundary. A new form of the full nonlinear dynamic free surface boundary condition is used to describe the evolution of tangential velocities. This alternate method solves for flows with field singularities more easily than the conventional method, which uses the complex velocity potential. Also, the velocity field is given directly without the need for numerical differentiation. Under the new formulation, the dynamic free surface boundary condition does, however, become more complicated. As a result, while the new form of the boundary element method has definite advantages for fixed boundaries, its usefulness for free surface problems is mixed.

Physics of Fluids

Deformation of a Free Surface as a Result of Vortical Flows

by

Assistant Professor Gretar Tryggvason

The deformation of a free surface caused by the roll up of a vortex sheet below the surface is studied. The large amplitude motion depends on both the strength and depth of the vortex sheet. A distinction is made between three different scenarios of the free-surface motion: a breaking wave, entrainment of air, and the generation of relatively short surface waves.

Chapter in Book
Mathematical Aspect of Vortex Dynamics
edited by R. Caflish, SIAM

Vortex Dynamics of Stratified Flows

by

Assistant Professor Gretar Tryggvason

After a brief review of vortex methods for stratified flows, recent work on the evolution of vortical flows in the vicinity of density interfaces and free surfaces is discussed. Two specific examples are considered: free surface deformation due to the roll up of a submerged vortex sheet, and the mixing across a weak density interface due to the head-on collision of vortex pairs and vortex rings. The conclusion discusses boundary integral methods for three-dimensional flows, as well as alternative vorticity formulations for general stratified flows.

Ph.D. Dissertation
Department of Mechanical Engineering and Applied Mechanics
The University of Michigan

Unsteady Separated Flow Around a Two-Dimensional Bluff Body Near a Free Surface

by

Graduate Student Seok Won Hong

This thesis deals with unsteady two dimensional separated flows past bluff bodies under a free surface. The primary objective of this work is to develop a reliable mathematical and numerical model to accurately predict the important elements of these flows, such as the hydrodynamic loading on the body, vortex shedding frequency, and the shape of the free surface. Another objective is to study the interactions between the free surface and the body, the vortical wake, and the viscous boundary layer.

The mathematical model is developed using several assumptions for the flow and the free surface boundary condition. The flow is assumed to be incompressible and at a high Reynolds number, so that it is irrotational except within the very thin boundary layer around the body surface and the vortical wake behind the body. The vortical wake is further assumed to be an irrotational flow with a number of inviscid circular vortices of finite core size. The free surface between the water and air is assumed to satisfy the full nonlinear boundary conditions, but the effects of surface tension are ignored.

The numercial model is formulated by using the most appropriate numerical methods and schemes. A complex variable boundary integral method is used for the estimation of flow velocities. A boundary layer solver is used to define the location and rate of vorticity shedding at the flow separation points. A Lagrangian scheme is used to evolve the free surface and the vortical wake. A fourth-order Runge-Kutta scheme is used for higher resolution time stepping.

The present numerical model is found to be successful for various numerical calculations and verifications. The hydrodynamic loading on the circular cylinder below a free surface is correctly estimated both with and without shed vortices. The vortex-free surface interactions are compared with the linearized solutions and shown to agree accurately with them.

ONR CODE 12 SHIP WAKE CONSORTIUM

1988 FALL WORKSHOP

University of Michigan
David Taylor Research Center
Naval Research Laboratory

October 4 & 5, 1988

College of Engineering (North Campus)
University of Michigan
Ann Arbor, MI 48109

AGENDA

Tuesday, October 4 - Boulevard Room, North Campus Commons

0830	Introduction and Opening Remarks R.F. Beck, UM	
0845	ONR Surface Ship Wake Detection Program D.H. Johnson, ONR	
0915	Summary of the DTRC Kelvin Wave Computation Workshop A.M. Reed, DTRC	
1015	Coffee Break	
1030	Kelvin Wake Ship Model Tests at DTRC T. Ratcliffe, W. Lindenmuth, DTRC	
1130	Nonlinear Surface Wave Computations W.W. Schultz, R.F. Beck, UM	
1215	Lunch	
1330	Full Scale Wake Measurements using the ERIM Airborne SAR and DARTS J.D. Lyden, ERIM; G.A. Meadows, L.A. Meadows, K.-P. Beier, UM	
1415	Observational Characteristics of SIR-B SAR Images K.R. Nicolas, NRL	
1500	Coffee Break	
1515	Modification of Surface Wave Number Spectra by Ship Wake Currents O.M. Griffin, NRL; R.A. Skop, U. of Miami	
1600	Radar Measurements of Model-Scale Wakes W. Lindenmuth, DTRC	
1630	Full Scale Measurements of Short Waves in Wakes J. Milgram, MIT	

Wednesday, October 5 - Room 134, NAME Department, North Campus

0830	Field and Laboratory Measurements of Surface Foam in Sea Water R.D. Peltzer, NRL; D.T. Rowley, UM
0915	Near Field Turbulent Ship Wake Computations M.B. Stewart, NRL
1000	Coffee Break
1015	Turbulent Ship Wake Predictions using SURFWAKE A.W. Troesch, UM; E.W. Miner, T.F. Swean, Jr., NRL
1045	Propeller Wake Measurements J. Blanton, S. Fish, DTRC
1145	Lunch
1300	Model Scale Free Surface Wake Measurements using DARTS A.W. Troesch, G.A. Meadows, L.A. Meadows, K.-P. Beier, UM
1345	PSH Laser-Doppler Anemometer Design W.W. Willmarth, UM
1415	Summary and Discussion
1445	Informal Demonstration at the Laser Flow-Visualization Facility L.P. Bernal, W.W. Willmarth, UM